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CONGESTED PUBLIC GOODS: THE CASE OF
FIRE PROTECTION

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Department of Economics

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Summary:

For a pure public good, individual consumption is insensitive to the size of the consuming group, holding public good output fixed. Most publicly-provided goods, however, are subject to congestion; consumption falls, holding output fixed, as the number of consumers increases. In this paper, the strength of congestion for municipal fire protection is measured by regressing a proxy for the consumption of protection (the municipal fire insurance rating) on a fire suppression capacity measure and population. The results suggest that the congestion properties of fire protection are much like those of a pure public good. In addition, a new notion of returns to scale for local public goods is developed, and evidence on returns to scale for fire protection is presented.

Congested Public Goods: The Case
of Fire Protection

by

Jan K. Brueckner¹

While individual consumption of a Samuelsonian pure public good is insensitive to the size of the consuming group, some recent empirical work in local public finance realistically incorporates congestion effects: individual public good consumption falls, holding public sector resources fixed, as the size of the consuming group increases. In two important recent papers in this Review, Bergstrom and Goodman (B-G) and Borchering and Deacon (B-D) attempted, among other things, to estimate the strength of congestion for various public goods.² Both papers postulated that the consumption level of a public good equals Xn^γ , where X is a measure of public output, n is the size of the consuming group, and $\gamma \leq 0$. Both papers assumed in addition that as a result of a majority voting process, public good consumption in a community is set at the level desired by the voter with the median income. A public good demand function was then used to derive an estimating equation relating public expenditure to a community's median income level, population, and other variables. The congestion parameter γ was estimated by a non-linear function of the regression coefficients from this equation.

While this procedure has the advantage that it permits estimation of γ without direct measurement of the level of consumption of the public good, it may lead to serious error. First, if the median voter model is a faulty representation of the public choice process at the local level, conclusions about public good congestion based on the empirical results

are invalid. Second, even when the median voter model is appropriate, if the public good demand function does not have the constant-elasticity form imposed in both papers, then the estimating equations will be misspecified, complicating the interpretation of the empirical results. The present study eliminates these possible sources of error by using a proxy for public good consumption to directly estimate the technological relationship between consumption, public good output, and population. The paper studies municipal fire services and uses a community's fire insurance rating as a proxy for public consumption, which is taken to be the level of fire protection enjoyed by community residents. The empirical results suggest that the congestion properties of fire protection are close to those of a pure public good. In addition, the paper introduces a new notion of returns to scale for public goods and provides evidence on returns to scale for fire protection.

Section I presents a general model of a congested public good, Section II extends the model to the fire protection case, and Section III presents and analyses the empirical results.

I. A General Model

The most general form of the expression giving the consumption level of a congested public good is

$$z = f(X, n, S), \tag{1}$$

where z is consumption, X is public good "capacity," a measure of physical output, n is the consuming group size, and S is a vector of environmental variables which affect the consumption level afforded by a given capacity. In the case of public parks, for example, S could include a measure of

climate conditions, which clearly affect the benefits afforded by a given park capacity. In the case of fire protection, S will be an index of fire hazards. Note that (1) implicitly requires identical consumption of the public good by all members of the consuming group. Unfortunately, models where public consumption may be unequal (see Oakland) are too complicated for empirical testing. Equal consumption appears in any case to be a fairly realistic assumption.

Public good congestion implies $f_2 \leq 0$, and since a larger capacity raises consumption, other things equal, $f_1 > 0$. A likely range for the strength of congestion effects emerges from considering the elasticity of consumption with respect to n for the polar cases of private and pure public goods. Ignoring S for the moment, a publicly-provided private good which is divided equally among members of the consuming group satisfies $z = X/n$. In this case, the elasticity of consumption with respect to n or "elasticity of congestion," which is given by $\frac{n}{z} \frac{\partial z}{\partial n}$, equals -1 . A one percent increase in the group size reduces consumption by one percent, holding capacity fixed. For a pure public good, $z \equiv X$ and the elasticity of congestion equals zero. It seems reasonable to suppose that all publicly-provided goods have congestion properties which are intermediate between the extreme cases of private and pure public goods. Letting γ denote the congestion elasticity $\frac{n}{z} \frac{\partial z}{\partial n} \equiv \frac{nf_2}{f}$, which depends in general on X , n , and S , this assumption means $-1 \leq \gamma \leq 0$.

A natural notion of returns to scale for local public goods also emerges from (1). Assuming that f is homogeneous of degree k in X and n , the public good will exhibit $\left. \begin{array}{l} \text{increasing} \\ \text{constant} \\ \text{decreasing} \end{array} \right\}$ "returns to scale in

consumption" as $k \geq 0$, meaning that consumption $\left. \begin{array}{l} \text{increases} \\ \text{stays constant} \\ \text{decreases} \end{array} \right\}$ when X and n are increased by the same proportion. While the specification $z = Xn^\gamma$ used by B-G and B-D implies non-decreasing returns to scale in consumption when $-1 \leq \gamma \leq 0$, the more general framework used here does not rule out decreasing returns. It is interesting to note that the degree of returns to scale in consumption tells how public consumption varies with community population when per capita public good capacity is held constant. This follows because $X/n = v$ means consumption may be written $f(vn, n, S) = n^k f(v, 1, S)$. Consumption will $\left\{ \begin{array}{l} \text{increase} \\ \text{stay constant} \\ \text{decrease} \end{array} \right\}$ with the size of the community, holding X/n fixed, as $k \geq 0$.

It is important to realize that returns to scale in consumption and returns to scale in the production of public good capacity are unrelated concepts. The latter issue must be considered, however, in deriving an estimating equation from (1), as will become clear shortly.³

II. The Case of Fire Protection

The adequacy of fire protection in municipalities in many states is evaluated by the Insurance Services Office (ISO). The resulting municipal fire insurance rating is an important determinant of the fire insurance premiums paid by property owners. In a competitive insurance market, premiums for a structure should bear a close relationship to expected fire losses. The use of the ISO rating in computing premiums indicates that it is a predictor of expected losses and hence a measure of a community's level of fire protection. The rating is computed by comparing the characteristics of a community's fire department, water supply, and fire communications system, as well as its level of fire hazards, to ideal standards. Deficiency points are subtracted from an

initial point total for shortcomings in each category. The fire department and water supply each account for 39% of the total possible deficiency points, while fire communications and fire hazards account for 9% and 13% respectively. Communities are rated on a one to ten scale on the basis of their point score, with a higher number indicating a poorer rating. This inverse relationship was reversed by constructing an index of fire protection equal to ten minus the ISO rating. This index is used to represent z in the empirical work.

The method of computation of the ISO rating indicates that a community's ability to suppress fires depends jointly on the characteristics of its water supply and fire department. A modern, well-staffed fire department may be relatively ineffective in a community with poor water pressure, while the fire fighting ability of a poorly-operated fire department may be enhanced by a water system which permits the use of large quantities of water at the scene of a fire. Accordingly, it is assumed that a community's fire suppression capacity X is given by

$$X = G(F,W), \quad (2)$$

where F represents fire department pumping capacity, W represents the delivery capacity of the water supply system, and $G_1, G_2 \geq 0$. It will be assumed that G exhibits constant returns to scale; doubling F and W doubles fire suppression capacity. As will be seen below, this assumption simplifies the discussion of returns to scale in consumption. While direct observation of F and W is usually impossible, water supply and fire department expenditures are readily available and can be used to deduce the levels of F and W . Assuming that fire department pumping

capacity is produced using inputs of capital and labor and that fire departments minimize the cost of providing a given level of pumping capacity, then fire department expenditures, FEX, are given by

$$FEX = C(F,p), \quad (3)$$

where C is the cost function for pumping capacity and p is the wage of fire fighters. Since the price of fire department capital inputs will be approximately uniform across communities, it need not appear explicitly in the cost function.⁴ It is interesting to note that while substitution possibilities between labor and capital in the production of pumping capacity appear to be limited, fire departments are able to economize on labor inputs by under-manning their companies, a practice which is noted by the ISO in assigning deficiency points. Another point is that it may be unrealistic to model a government agency as a cost-minimizer. Unfortunately, even though the pressure to keep costs low may be relatively weak in local government, it is impossible to deduce capacity levels from available data without the assumption of cost-minimization.

Assuming that water supply capacity is produced with capital and labor, water supply expenditures, WEX, are given by

$$WEX = H(W,q), \quad (4)$$

where H is the cost function and q is the wage of water supply workers.⁵ Since $C_1, H_1 > 0$, (3) and (4) may be inverted to yield $F = \tilde{C}(FEX,p)$ and $W = \tilde{H}(WEX,q)$. Letting both p and q be represented by the average wage for local government workers, y, for which data are available, (2) may be written

$$X = G(\tilde{C}(FEX, y), \tilde{H}(WEX, y)). \tag{5}$$

Substituting in (1) yields

$$z = f(G[\tilde{C}(FEX, y), \tilde{H}(WEX, y)], n, S), \tag{6}$$

an equation which contains only observable variables.

While a regression based on (6) will yield an estimate of the elasticity of congestion, estimating the degree of returns to scale in consumption requires the further assumption of constant returns in the production of both fire department and water supply capacity. Under these assumptions, $FEX = c(y)X$ and $WEX = h(y)X$, giving

$$z = f(G[FEX/c(y), WEX/h(y)], n, S) \tag{7}$$

$$\equiv L(FEX, WEX, n, y, S).$$

Since G exhibits constant returns to scale, increasing FEX and WEX by a given proportion results in an equal proportional increase in X . Consequently, the degree of homogeneity of L in FEX , WEX , and n gives the degree of homogeneity of f in X and n , which is the degree of returns to scale in consumption. Although constant returns in the production of capacity is a strong assumption, the degree of returns to scale in consumption cannot be deduced from regression results without it. B-G and B-D also found it necessary to assume that public good capacity is produced with constant returns.

In the next section, results from estimating

$$z = aFEX^\alpha WEX^\beta n^\gamma y^\eta S^\delta \tag{8}$$

are reported. This equation may be derived by assuming $f(X, n, S) \equiv AX^{b_1} n^{b_2} S^{b_3}$, $G(F, W) \equiv BF^d W^{1-d}$, $F = DL_F^m K_F^{1-m}$, and $W = TL_W^r K_W^{1-r}$, where K_F , L_F , K_W , and L_W are capital and labor inputs for fire and water supply capacity, and all parameters except b_2 are positive. The fire and water supply cost functions are proportional to Fy^m and Wy^r , respectively, and substitution yields (8). In particular, $\alpha = b_1 d > 0$, $\beta = b_1(1-d) > 0$, $\gamma = b_2 < 0$, $\theta = -b_1(dm + (1-d)r) < 0$, and $\delta = b_3$, which is positive when S is taken to be a decreasing measure of fire hazard. Note that γ is the elasticity of congestion and that $\alpha + \beta + \gamma = b_1 + b_2$ gives the degree of returns to scale in consumption.⁶

Intuition suggests that fire protection exhibits substantial publicness, implying that γ ought to lie closer to zero than to -1. This seems likely because fire suppression capacity is used relatively infrequently, with fire department equipment and personnel sitting idle much of the time. Thus, increasing the size of a community while holding its fire suppression capacity fixed should not markedly decrease the level of protection provided to each resident. Intuition does not seem similarly capable of predicting the degree of returns to scale in consumption.

III. Empirical Results

Data on FEX, y , and n were taken from the 1972 Census of Governments. This source also gives municipal water supply expenditures broken down into current operating expenditures, expenditures for capital improvements, and debt service. The last two components vary erratically across communities, presumably as a result of the cyclical

nature of new construction and differences in age and financing methods among water supply systems. The level of current operating expenditures appeared therefore to be the most reliable indicator of effective water supply expenditure, and consequently it was used to represent WEX.

The fire hazard component of the ISO rating is principally based on the extent of industrial fire hazards, the nature and enforcement of building laws and heating and ventilation regulations, and the scope of preventive building inspections. Since direct data on such variables are not generally available, the search for a hazard index was restricted to variables thought to measure the fire-worthiness of a community's housing stock. The three variables considered were the fraction of a community's 1970 dwelling units constructed before 1939, the fraction of 1960 units that were sound with all plumbing facilities (this variable unfortunately was not computed in the 1970 Census of Housing), and the fraction of 1970 units with less than 1.01 persons per room. The last variable, which measures the extent of crowding in the housing stock and presumably assumes a low value in communities with relatively large proportions of run-down housing, was significant with the correct sign in all the regressions. Since the first two variables were never significant and their inclusion had a negligible effect on the estimated coefficients of the other variables, the regressions reported below use the crowding variable as the only measure of fire hazard.^{7,8}

Since only current fire insurance ratings are available from the Insurance Services Office, the fire protection index used in the regressions is based on 1978 ratings. However, since changes in a community's rating occur infrequently, the 1978 ratings can be used with 1972 expenditure data without serious error.

The sample contains 100 communities with populations exceeding 30,000 in the states of Illinois, Indiana, Wisconsin, and Michigan.⁹ Small communities were deleted because they are likely to have all- or partly-volunteer fire departments, with the result that fire department expenditures no longer bear a close relationship to department capacity. The reasonableness of the population cutoff point of 30,000 is suggested by detailed fire department personnel data from Texas, one of the few states which collects such information.¹⁰ In 1972, Texas had 39 cities with populations above 30,000, and of these, only five had fire departments with volunteer personnel. Three were roughly half-volunteer, half-paid, one was mostly-volunteer, and one was all-volunteer. While the frequency of volunteer fire departments in the Midwest may be different than in Texas, deleting cities below 30,000 should generate a sample with few all- or partly-volunteer fire departments.

Communities were also deleted from the sample if their water supply system was operated by a private company, making water supply expenditure data unavailable. Since the vast majority of communities operate their own water supply systems, deletions for this reason were not extensive.

The first row of Table 1 gives the parameter estimates based on the entire sample. The estimated coefficients indicate as expected that, ceteris paribus, the level of fire protection in a community increases with level of fire and water expenditures and decreases as fire hazards and population increase (recall that the crowding variable is a decreasing measure of fire hazard). The magnitude of $\hat{\gamma}$, the estimate of elasticity of congestion, is especially striking. The estimated value of about $-.24$ indicates as predicted that fire protection has congestion

properties more like those of a pure public good than a private good. A 1% increase in community population causes approximately a 1/4% decrease in the level of fire protection, holding fire suppression capacity and the level of fire hazards constant. Although the estimate of the elasticity of congestion is negative, it is interesting to note that the simple correlation between population and the fire protection index is positive; large communities tend to have better fire insurance ratings than small ones.¹¹ A 95% confidence interval for γ is contained in the first row of Table 2. While the confidence interval is fairly wide, it lies well to the right in the interval $[-1,0]$, indicating substantial publicness.

The estimated wage coefficient, while negative, is unfortunately not significantly different from zero, contradicting the prediction of a negative wage effect. While this appears to violate the model, an explanation may be that higher wages are associated with better labor quality. Holding expenditures fixed, fire suppression capacity need not fall as the wage increases if labor quality increases simultaneously.

The estimate of the degree of returns to scale in consumption, $\hat{\alpha} + \hat{\beta} + \hat{\gamma}$, is significantly positive and equal to about .16, indicating increasing returns: equal proportional increases in fire suppression capacity and population lead to an increase in the level of fire protection. Or, holding per capita fire suppression capacity fixed, the level of fire protection increases with the population of the community.

While the fire insurance ratings of all but two communities in the sample are less than or equal to 6, with 4's and 5's being most common,

one small community has a rating of 7 and another has a rating of 9, one point away from the worst possible rating. Deletion of the latter community changes some of the estimated coefficients, as the second row of Table 1 shows. The estimated elasticity of congestion rises to about $-.11$, but the parameter is still significantly different from zero. The most striking change is in the estimated the water supply coefficient, which, while negative, is no longer significantly different from zero. Although this change appears to contradict the model, an explanation is suggested by the fact that the deleted community's poor insurance rating was accompanied by extremely low water supply expenditures. Deletion of the community eliminated the positive association in the data between WEX and the fire protection index, an outcome which makes sense under the supposition that the extra fire suppression capacity afforded by additional water supply capacity is zero in communities with reasonably good insurance ratings, such as those in the restricted sample. In other words, it is likely that water supply systems are good enough in these communities that the marginal productivity of water supply capacity in fire suppression equals zero, explaining the zero WEX coefficient for the restricted sample. Inclusion in the sample of a community with a poor water supply system, however, causes the regression to pick up the positive effect of WEX on the fire protection index which is felt in communities with poor water supply systems.

Further restriction of the sample to communities with populations exceeding 45,000 leads to qualitatively similar results, which are

shown in the third row of Table 1. The signs of significant coefficients remain the same, with the point estimate of the congestion elasticity falling to about $-.19$. Confidence intervals for γ in the two restricted samples are contained in the second and third rows of Table 2, and their location toward the right end of the interval $[-1,0]$ further supports the conclusion that the congestion properties of fire protection are much like those of a pure public good.

Since the marginal productivity of water supply capacity appears to be zero in the restricted samples, returns to scale in consumption is appropriately defined in terms of fire department capacity and population. The sum of α and γ thus gives the degrees of returns to scale in consumption, with the estimates in the second and third rows of Table 1 indicating increasing returns. Increasing fire department capacity and population by the same proportion leads to a higher level of protection. Or, holding per capita fire capacity (and thus per capita fire expenditures) fixed, higher levels of protection are achieved in larger communities.

These results on returns to scale in consumption are consistent with conclusions reached by Will. He computed the per capita cost of providing a level of fire department capacity considered acceptable under National Board of Fire Underwriters standards, regressed this variable on population, and viewed the resulting negative relationship as evidence of what he called returns to scale. Since with increasing returns in consumption, a given per capita fire expenditure yields a higher level of protection in a larger community, Will's result that the ideal NEFU protection level can be provided at lower per capita cost in a larger community follows immediately. This consistency of results is

not surprising in view of the fact the MEFU standards are used in computing the ISO ratings.

Borcherding and Deacon estimated the congestion elasticity for fire protection, and although tests of hypotheses about the parameter are not completely reliable because the distribution of its estimator is unknown, the elasticity appears not to be significantly different from -1. This counter-intuitive conclusion, which says that fire protection has congestion properties like those of a private good, is obviously at odds with the above results.¹²

IV. Conclusions

This study has provided the most reliable evidence to date on the congestion properties of a local public good. It has been shown that fire protection exhibits substantial publicness, with 95% confidence intervals for the elasticity of congestion lying well to the right in the interval $[-1,0]$. This result conforms well to intuition, which suggests that because the demands on fire suppression capacity are relatively infrequent, increasing a community's population should not greatly reduce the level of fire protection, holding suppression capacity fixed.

It has also been shown that fire protection exhibits increasing returns to scale in consumption. When attention is restricted to communities with relatively good fire insurance ratings, this means that the level of fire protection increases with the size of the community, holding per capita fire expenditures fixed. It follows that a given level of fire protection may be provided at a lower per capita cost in a larger community. This result is obviously extremely useful for long range government planning in a growing community.

Finally, the results in this paper bear on the issue of optimal city size. The congestion properties of local public goods must be considered in any theoretical model where city population is chosen to maximize the welfare of urban residents. If local public goods exhibit a high degree of publicness, optimal size cities will be relatively large (see Alonso).

Footnotes

¹Assistant Professor of Economics, University of Illinois at Urbana-Champaign. I wish to thank Mark Browning for several useful discussions. Any remaining errors are my own.

²Congestion effects also play a role in the specification of the empirical models of Brueckner and Deacon.

³It should be noted that one common notion of returns to scale in the empirical literature bears no relation to either of the above returns to scale concepts. Hirsch (1959, 1968) and Riew regress per capita expenditure for various local public services on population and a variety of other explanatory variables, viewing negative population coefficients as evidence of what they call increasing returns to scale. Assuming constant costs for capacity X , this procedure tells only how per capita capacity varies with community population and provides no evidence whatsoever about underlying technological relationships. With non-constant capacity costs, the population coefficients have no clear interpretation at all.

Walzer uses the less objectionable approach of regressing cost per unit of police services on the level of police services and other variables. Since the police service measure is a composite index which incorporates both capacity and consumption variables, the relation of Walzer's approach to the above is unclear.

⁴Although the price of structure capital (fire stations) may vary across communities, the price of rolling stock and other equipment is set in national markets.

⁵While the price of some water supply capital inputs may vary across communities, this is ignored in (4).

⁶The multiplicative form of (6) is consistent with the computation of the ISO rating since extra deficiency points are levied depending on the extent of divergence between the qualities of the fire department and water supply. Since a poor water supply, for example, is thought to limit the contribution of the fire department, a multiplicative expression such as (6) is appropriate.

⁷The lack of explanatory power of the age distribution variable might follow from a weak relationship between the level of maintenance of a community's housing stock and its age. The dilapidation measure might be insignificant due to its use of 1960 data. Structures dilapidated in 1960 may well have disappeared by 1972.

⁸It should be noted that since fire fighting in high-rise buildings requires advanced equipment, a given level of fire expenditures affords less protection in a community of fixed size the greater the proportion of high-rise structures. However, the number of high-rise buildings will be roughly constant across communities of a given population,

although it will increase with community size. We may therefore ignore the frequency of high-rise buildings and treat the vertical growth of a city which accompanies population growth as just another cause of congestion in fire protection.

⁹Climate is an environmental variable which affects the fire protection afforded by a given fire suppression capacity since many fires are caused by problems in furnaces. The uniformity of climate in the sample means its effect need not be considered.

¹⁰Regressions using the insurance rating index compiled by the Texas state government yielded very poor results, with none of the independent variables exhibiting any explanatory power.

¹¹It is interesting to note that deletion of Chicago, whose population is nearly three times as large as the next largest city in the sample (Detroit), does not substantially change the regression results.

¹²In his study of the economics of fire protection, Ahlbrandt regressed community per capita fire expenditure on population, the fire insurance rating, and a host of other variables. Unfortunately, the inclusion of independent variables such as assessed property value and fire department characteristics makes Ahlbrandt's results inappropriate for answering the questions addressed in the present paper.

However, in a study of New York state school districts, Kiesling computed regressions which provide evidence on congestion and returns to scale in consumption in education. Since he was not cognizant of the theoretical issues discussed in the present paper, Kiesling was not aware of the following interpretation of his results. His procedure was to regress a composite measure of student performance on standardized tests (a measure of education consumption) on school district enrollment, expenditure per pupil, and an index of average student intelligence. The use of expenditure per student means that the coefficient of enrollment gives the degree of returns to scale in consumption while the difference between the coefficients of expenditure per student and enrollment gives the elasticity of congestion. The degree of returns to scale is significantly negative, in contrast to the case of fire protection, while the point estimate of the congestion elasticity is considerably less than -1. It is not possible, however, to deduce whether the elasticity is significantly different from -1 without more statistical information than is provided in the paper.

TABLE 1 - ESTIMATED COEFFICIENTS

Variable	FEX	WEX	n	y	S	-
Parameter	α	β	γ	θ	δ	$\alpha + \beta + \gamma$
Interpretation	-	-	elasticity of congestion	-	-	degree of returns to scale in consumption
d.f. = 94	.1930*	.2021*	-.2379*	-.0343	1.3220*	.1572*
R ² = .4631	(3.235)	(3.979)	(-3.281)	(-.263)	(1.914)	(5.559)
d.f. = 93	.2848*	-.0530	-.1143*	.1215	1.2719*	-
R ² = .5974	(7.100)	(-1.307)	(-2.333)	(1.394)	(2.798)	(4.171)
d.f. = 56	.3158*	.0046	-.1878*	-.0509	1.1857*	-
R ² = .6137	(5.635)	(.092)	(-2.844)	(-.424)	(2.019)	(2.602)

* - indicates coefficient estimate significantly different from zero at 5% level, two-tailed test (t-ratios in parentheses).

All variables in log form. FEX, WEX are in units of \$100,000, n is in units of 10,000, y (monthly wage) is in units of \$100, S is percent of dwellings with persons per room less than 1.01, and dependent variable is 10 minus the ISO rating.

TABLE 2 - 95% CONFIDENCE INTERVALS
FOR ELASTICITY OF CONGESTION

<u>Interval</u>	<u>d.f.</u>
[-.3829, -.0929]	94
[-.2123, -.0163]	93
[-.3198, -.0558]	56

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